Supplementary Materials

Are capuchin monkeys (*Sapajus* spp.) sensitive to lost opportunities? The role of opportunity costs in intertemporal choice

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Pilot study

About seven years before the current study, we carried out a pilot experiment involving_7 of the 10 subjects that participated in the current study.

Subjects

We tested 10 adult capuchin monkeys, belonging to four social groups, housed at the Primate Center of the Consiglio Nazionale delle Ricerche, Rome (Table S1). All subjects had extensive experience in cognitive tasks and most of them had previously participated in studies in which the delay choice task was employed (seven subjects participated in Addessi et al. 2011 and, among these, two subjects also participated in Amici et al. 2008). Three subjects did not have previous experience with the delay choice task. One subject (Pippi) died during the study, and she did not complete all the experimental conditions. Her data were thus excluded from the analyses, which are based on a sample of nine subjects.

Apparatus

We used the same apparatus as in the main experiment. However, in the pilot experiment food options were not covered by colored cups, but they were fully visible to the subject at the time of choice.

Procedure

We used the same procedure as in the main experiment, although with two exceptions: the order in which the three conditions were presented was partially counterbalanced across subjects (rather than fully counterbalanced), by assigning different groups of subjects (as heterogeneous as possible for sex and social group) to one of the three orders of condition presentation (Table S1) and subjects were tested in 10 sessions for each experimental conditions (rather than up until reaching a stability criterion, as in the main experiment). Data collection was carried out between June 2011 and February 2012.

Table S1: Subjects' sex, age (years), and presentation order

Subject	Sex	Age	Order of condition presentation
Carlotta	F	27	*High*, *Low cost different*, *Low cost same*
Gal	M	21	*Low cost same*, *High*, *Low cost different*
Paprica	F	22	*Low cost different, Low cost same, High*
Pedro	M	10	*Low cost different, Low cost same, High*
Pippi*	F	29	*Low cost same*, *High*, *Low cost different*
Robin Hood	M	14	*High*, *Low cost different*, *Low cost same*
Robinia	F	17	*High*, *Low cost different*, *Low cost same*
Robot	M	16	*Low cost different, Low cost same, High*
Sandokan	M	11	*High*, *Low cost different*, *Low cost same*
Saroma	F	10	*Low cost same*, *High*, *Low cost different*

* Pippi died during the study and did not complete all the experimental conditions

Results and Discussion

For each condition and subject, we calculated the mean proportion of choice of the larger, later option. Since the residuals were normally distributed (Shapiro-Wilk test: $W = 0.95$, $p = 0.17$) and the variances were homogeneous (Levene's test: $F_{2,6} = 0.45$, $p = 0.88$), we performed a mixed-model ANOVA with the experimental condition as a within-subject factor and the order of condition presentation as a between-subject factor.

There was a significant main effect of experimental condition ($F_{2,12} = 6.68$, $p = 0.01$, $\eta_p^2 = 0.46$). Capuchins chose the larger option significantly more in the *Low cost same* condition than in the *High cost* condition (Tukey post-hoc test, $p = 0.04$, $h = 0.23$), but they did not differ between the *High cost* and *Low cost different* conditions (Tukey post-hoc test, $p = 0.29$) or between the *Low cost same* and *Low cost different* conditions (Tukey post-hoc test, $p = 0.64$). There was no significant effect of the order of condition presentation ($F_{2,6} = 0.82$, $p = 0.48$), whereas there was a significant condition by order interaction ($F_{4,12} = 3.97$, $p = 0.03$, $\eta_p^2 = 0.57$).

The pattern of our results did not completely fit any of our predictions (as reported in the main text, Introduction). Surprisingly, choice in the *High cost* condition and the *Low cost different* condition did not differ. Capuchins may have not discriminated the difference between the *High cost* and the *Low cost different* conditions since in both conditions they were presented with one food item (available after 2 seconds) and six food items (available after 80 seconds), and no cue signaled the difference between conditions – with the exception of the possibility of performing additional choices during the delay in the *Low cost different condition*. In contrast, capuchins may have discriminated the difference between the *Low cost same* condition (three food items available after 2 seconds vs. six food items available after 80 seconds) and the *High cost* condition (one food item available after 2 seconds vs. six food items available after 80 seconds), possibly because the different numerosity of the smaller options may have helped capuchins to set these conditions apart. In order to facilitate subjects to discriminate between the contingencies of each condition, in the main study, reported in the present paper, we decided to cover the smaller, sooner and the larger, later options with colored cups, differing across conditions. This allowed also to avoid that tolerance to delay could be at least partially confounded with impulsivity towards food quantity at the time of choice, as discussed for instance by Addessi et al. (2013, 2014), Bramlett, Perdue, Evans, & Beran (2012), and Genty, Karpel, & Silberberg (2012).

Main study

R and packages

We used R (Version 4.0.2; R Core Team, 2020) and the R-packages *BayesFactor* (Version 0.9.12.4.2; Morey & Rouder, 2018), *bayestestR* (Version 0.7.0; Makowski et al., 2018), *brms* (Version 2.13.0; Bürkner, 2017), *emmeans* (Version 1.4.8; Lenth, 2020), *foreach* (Version 1.5.0; Microsoft & Weston, 2019), *here* (Version 0.1; Müller, 2017), *lme4* (Version 1.1-23; Bates, Mächler, Bolker, & Walker, 2015), *papaja* (Version 0.1.0.9997; Aust & Barth, 2018), and *tidyverse* (Version 1.3.0; Wickham et al., 2019) for all our analyses.

Supplementary results

Figure S1 illustrates individual choice proportions per session and condition.

Post-hoc, exploratory analyses

As a post-hoc, exploratory analysis, we included the subjects' choice in the previous trial as a predictor in our final accepted model (random effect: subject, fixed effect: condition). Using forwards and backwards selection, we found that, when including all subjects, the model with condition and previous choice outperformed condition only ($X^2 = 10.55$, $p = 0.001$, $BF = 43.3$). However, when the outlier subject Robot was removed, the frequentist analysis did not detect a difference between the condition-only and the condition and previous choice model ($X^2 = 2.63$, $p = 0.11$), and the Bayesian analysis did not provide evidence for either model over the other ($BF = 0.84$).

In Table S4, we have reported the number of left/right choices for each subject across the three conditions. Most of the subjects did not show a consistent side bias, with the only exception of three subjects in the *Low cost different* condition.

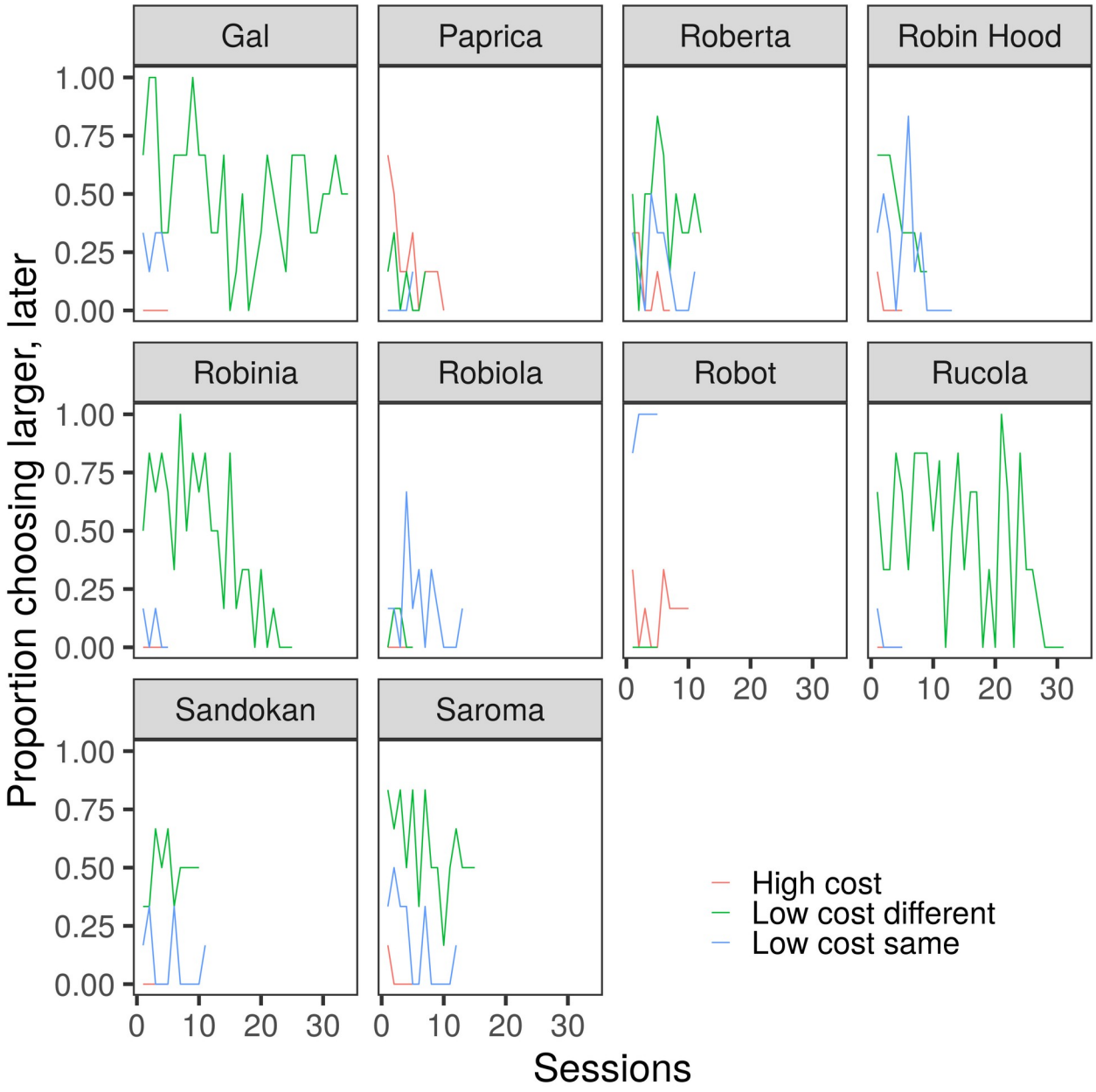

Figure S1. *Choice proportions per session and condition. Capuchins were tested up until a criterion of five consecutive sessions in which the number of choices for the larger, later option diverged by no more than one unit.*

Table S2. Generalized Linear Mixed Models fit by maximum likelihood (Laplace Approximation).
Analysis for the whole sample
Family: binomial (logit)
Formula: choice ~ condition + (1 | subject)

AIC	BIC	logLik	Deviance	Df resid
637	656.2	-314.5	629.0	896

Random effects			
Groups	Name	Variance	Std. Dev.
Subject	(Intercept)	1.01	1.01

Number of observations = 900, groups: subjects = 10

Fixed effects	Estimate	Std. Error	z value	Pr (> | z |)
(Intercept)	-3.61	0.45	-8.08	<0.001
Condition *Low cost same*	1.61	0.34	4.69	<0.001
Condition *Low cost different*	2.21	0.33	6.63	<0.001

Table S3. Generalized Linear Mixed Models fit by maximum likelihood (Laplace Approximation).
Analysis without the outlier Robot
Family: binomial (logit)
Formula: choice ~ condition + (1 | subject)

AIC	BIC	logLik	Deviance	Df resid
478.2	497.0	-235.1	470.2	806

Random effects			
Groups	Name	Variance	Std. Dev.
Subject	(Intercept)	0.83	0.91

Number of observations = 810, groups: subjects = 9

Fixed effects	Estimate	Std. Error	z value	Pr (> | z |)
(Intercept)	-4.14	0.52	-7.93	<0.001
Condition *Low cost same*	1.18	0.48	2.45	0.014
Condition *Low cost different*	2.95	0.44	6.70	<0.001

Table S4. The table reports, for each condition and subject, the number of choices on the right side in each session (out of six trials) and the p value of the one sample Wilcoxon test (a significant p value, highlighted in bold, indicates that the subject exhibited a side bias)

Condition	**High cost**					**p**	**Low cost different**					**p**	**Low cost same**					**p**
Session	**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
Gal	3	3	3	3	3	1.0	0	0	5	0	0	0.066	3	5	2	3	4	0.41
Paprica	3	4	4	4	3	0.083	3	4	3	3	4	0.16	3	3	3	3	2	0.32
Roberta	3	3	4	3	3	0.32	4	5	3	4	5	0.063	4	3	3	3	4	0.16
Robin hood	2	3	3	3	3	1.0	1	1	1	2	2	**0.038**	3	3	3	3	3	1.0
Robinia	3	3	3	3	3	1.0	3	4	3	3	3	0.32	1	3	4	3	3	0.65
Robiola	3	3	3	3	3	1.0	3	4	2	3	3	1.0	4	3	3	3	4	0.16
Robot	5	2	4	4	4	0.16	3	3	3	3	3	1.0	4	3	3	3	3	0.32
Rucola	3	3	3	3	3	1.0	2	3	3	3	3	0.32	2	3	3	3	3	0.32
Sandokan	3	3	3	3	3	1.0	5	6	6	6	6	**0.034**	3	3	3	3	4	0.32
Saroma	2	3	3	3	3	0.32	0	1	0	0	0	**0.034**	3	3	3	3	2	0.32

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